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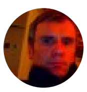

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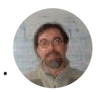

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Highlighting boundary condition effects for granular matter flows with numerical simulations

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Abstract

Granular matter flows naturally occur on small or large bodies due to gravity. Their simulation allows a better understanding of the dynamics of these bodies. However many numerical simulations operate with periodic boundary conditions for convenience, or with static grain boundaries that do not reproduce the rolling and friction effects expected at the interface. This work not only shows that boundary conditions have a long-range effect within the flow, but that dissipative effects induced by flat walls cannot be neglected compared to using static grain boundaries.

1. Introduction

Rubble pile asteroids, surface regolith, avalanches on larger bodies, are some naturally occurring examples of materials with a granular structure. The formation process and the dynamics of these assemblies of grains can be better understood through the use of numerical simulations [1]. The comprehension of the response of these materials when submitted to stress or collisions is of great importance for the success of future missions aiming at landing or sampling the surface of these bodies. Similarly the understanding of avalanches and other granular flows (ex: volcanism), is of interest not only for interpreting the geological features observed on planets like Mars, but is also with practical applications on Earth. Simulating granular flows therefore allows the scientist to develop an intuition of the dynamics of these systems, develop better models describing their long-term evolution, and ultimately make predictions from these models.

This work focuses on simulating flows of grains, with a particular attention on boundary conditions in the transverse direction. Many simulations [2,3] consider periodic boundaries for convenience. The implicit assumption is that far away walls do not impact the flow structure and therefore one can extrapolate the periodic simulation results to a large portion of the flow away from the boundaries. Experiments on the other hand [4] have shown a long-range influence of the boundaries within the flow (impact on the velocity for 2/3 of the grains), even for shallow flows comprising a few grain layers for large transverse sections (ratio about 1/10). Other simulations [3] consider boundaries covered by fixed grains. Compared to flat walls the rolling and friction effects are then similar within the flow and at the boundaries, artificially suppressing the discontinuity in grain behavior occurring along the walls. The results of these simulations therefore more closely resembles the periodic case. For natural systems the boundaries are rarely either perfectly flat or made of static grains. When simulating a natural flow of grains between rocks, one may expect that the boundary presents a discontinuity with the flow interior of an intermediate nature between flat walls and static grains. The limit case of static grains has been investigated, but few simulations consider flat walls. Understanding the response of the flow at this other limit offers an indication as to its behavior in the intermediate cases.

2. Simulation methodology

The following setup is used to simulate a granular matter flow and assess the influence of its boundaries:
– Grains are simulated as Discrete Elements [5]. They are modeled as soft spheres with a classical contact scheme by means of simulated springs and dashpots both in the normal and tangential directions.
– Unlike [3] the simulated grain physical properties match the experimental values given in [4] : normal and tangential coefficients of restitution, grain/grain and grain/wall friction coefficients.
– Grains with an initial random velocity are set above an inclined plane and let to evolve under simulated gravity. The system is cyclic along the flow direction. Walls may be added or not in the transverse direction.

The grain trajectories are then computed until either the system stops, reaches a steady state regime, or diverges. Which situation is actually reached depends on a global balance between: 1. the potential energy brought by simulated gravity (inclined plane); and 2. the energy dissipated by the collisions (coefficient of restitution <1) and friction (Coulomb's law). Steady states may be observed for a whole range of angles depending on the balance between the collision and friction effects. Fast flows at large angles are more collisional in nature, while slow flows at low angles depend more on frictional effects.

3. Results

Table 1: Periodic boundary results, height/with=1

μ_{gg}	μ_{gw}	Dispersity	θ_{min} in °	θ_{max} in °	Notes
0.4	0.4	mono	4.5	21.5	As in [2]
0.177	0.59	poly	6.5	21	More realistic than [2]
0.33	0.59	poly	6.5	24	Parameters close to [4]
0.33	0.59	poly	8	23	Rolling friction [6]

The first line in the table corresponds to the simulated conditions in [2] for comparison and validation. We then aim at reproducing the experimental range of angles (θ_{min},θ_{max}) obtained by [4] : from 15.5° to 20°. It is expected that a collisional friction coefficient between grains (μ_{gg}) better matches the experiments, as well and a value between dynamic and collisional friction coefficients for the wall (μ_{gw}). Even using the largest value (static friction) for both interactions is not enough to bring the lowest angles of steady state flows toward the experimental values. Adding a high amount of rolling friction [6] indeed increases the lowest angle but is still not sufficient. Some dissipative effect is missing.

Table 2: Large flow, low walls (7/30 ratio) results

μ_{gg}	μ_{gw}	Dispersity	θ_{min} in °	θ_{max} in °	Notes
0.177	0.59	poly	~8	~26	Transverse periodic
0.33	0.59	poly	~8	~23	Transverse periodic
0.177	0.59	poly	~14	>29	With walls
0.33	0.59	poly	~11	>29	With walls

As can be seen in table 2 walls indeed provide an important dissipative effect that cannot be neglected. The maximal angle of stability is now too large compared to the experiments. A reason may be the use of static friction (μ_{gw}=0.59) as explained above. Another the reduced size of the simulation compared to the experiment (7/30 height/wall ratio instead of 7/67). Investigation of these parameters is under way.

The velocity profile shows a shear flow (velocity increases with height), with an influence of the walls even at the middle of the flow (transverse section). For periodic boundaries a plug flow is observed instead: a block with higher and constant velocity on top of a rolling layer of grains. Influence of the walls therefore cannot be ignored both qualitatively (flow structure) and quantitatively (velocity profile).

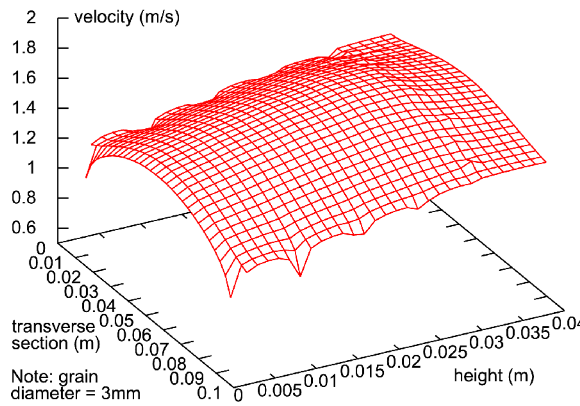

Figure 1: velocity profile

4. Discussion and conclusion

Surprisingly few studies have considered implementing flat boundaries for simulating granular flows [2], despite considerable practical and industrial interest. One possible reason is having to simulate the rolling and sliding effects as well as the different material properties at the boundaries. Another reason is the difficulty to interpret the results in the presence of a discontinuity in the grain dynamics at the boundary that makes it harder to attempt a formalization of a continuous rheology for granular flows [7, 4]. Nevertheless, our results show that proper modeling of the boundaries is necessary even for a first-order description of the flows in terms of elementary aspects like friction and dissipation. Therefore we argue that cyclic boundary conditions shall not be used without proper justification, especially in the light of the observed (both numerical and experimental) long-range effects of the boundaries within the flow structure.

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